Design of Non Linear Controller for a Satellite Attitude Control Simulator

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Abstract

The cost and error of the Satellite Attitude Control System design can be minimize by using ground test simulator. However, it construction difficulties are associated with creating zero gravity and no friction environments. Air bearing simulator provides the environment for investigation of satellite attitude dynamics and control problems. Large angle manoeuvre usually present highly non-linear plant and if the system parameters are not well determined the plant can also present some kind of uncertainty. As a result, controller designed by linear control technique can have its performance and robustness degraded. This paper presents the application of the State-Dependent Riccati Equation (SDRE) method to design and test an attitude control algorithm for 3-D satellite simulator. The simulator model is general since it is inertia moment dependent. The matlab/simulink simulator model is similar to 3-D INPE simulator which allows testing satellite hardware and software. The control strategy is based on gas jets and reaction wheel torques to perform three axes large angle manoeuvre. Simulation has investigated that SDRE controller performance and robustness for angular velocity reduction associated with stringent pointing requirement. This work served to validate the numerical simulator model and to verify the functionality of the control algorithm designed.

Keywords

SDRE Method; No Linear System; Satellite Control

Introduction

The design of satellite Attitude Control System (ACS), that involves plant uncertainties [1] and large angle manoeuvres following a stringent pointing control, may require new nonlinear attitude control techniques in order to have adequate stability, good performance and robustness. Experimental ACS design using non-linear control techniques through prototypes is the way to increase confidence in the control algorithm. Experimental design has the important advantage of allowing the satellite dynamics representation in laboratory, from which is possible to accomplish

different simulations to evaluate the satellite ACS [2]. However, the drawback of experimental test is the difficulty of reproducing zero gravity and torque free space condition. A Multi-objective approach [3] has been used to design a satellite controller with real codification. An investigated through experimental procedure has been used by [4] for simulator inertia parameters identification. An algorithm based on the least square method to identify mass parameters of a space vehicle in rotation during attitude manoeuvres has been developed by [5], a methods with the same objectives, but based on Kaman filter theory also has been investigated by [6]. The H-infinity control technique was used in [7] to design robust control laws for a satellite composed of rigid and flexible panels. The SDRE method is an approach that can deal with non-liner plant; it linearizes the plant around the instantaneous point of operation and produces a constant state-space model of the system similar the LQR [9] control technique. The process is repeated in the next sampling periods therefore producing and controlling several state dependent linear models out of a non-linear one. The SDRE method was applied by [8] for controlling a non-linear satellite system with six-degree of freedom. However, it did not incorporated the Kalman filter technique, such that it could work as state observer in conjunction with the SDRE method, allowing to take into account the non-linearities in the filter process. In this paper the SDRE controller associated with Kalman filter [10] are applied to design a non linear controller for a non-linear simulator plant where the unstructured uncertainties of the system are represented by process and measurements noise. As a result, the satellite attitude control algorithm design using the SDRE and Kalman filter techniques deal with large angle manoeuvre and plant uncertainties. The control strategy is based on reaction wheel and gas jets as actuator which allows to design two control algorithm related to the transition between high angular velocity

mode to the normal mode of operation with stringent pointing using an optimal control logic based on minimum system energy. Several simulations have proven the computationally feasibility for real time implementation of such control algorithm on satellite onboard computer [11].

SDRE Control Methodology

The Linear Quadratic Regulation (LQR) approach is well known and its theory has been extended for the synthesis of non linear control laws for non linear systems [8]. This is the case for satellite dynamics that are inherently nonlinear [12]. A number of methodologies exist for the control design and synthesis of these highly nonlinear systems; these techniques include a large number of linear design methodologies [13] such as Jacobian linearization and feedback linearization used in conjunction with gain scheduling [14]. Nonlinear design techniques have also been proposed including dynamic inversion and sliding mode control [15], recursive back stepping and adaptive control [16].

Comparing with Multi-objective Optimization Non-linear control methods [3] the SDRE method has the advantage of avoiding intensive interaction calculation, resulting in simpler control algorithms more appropriate to be implemented in satellite on-board computer. The SDRE linearizes the plant around the current operating point and creates constant state space matrices so that the LQR method philosophy can be used. This process is repeated in all steps, resulting in a point wise linear model from a non-linear model, so that the Riccati equation is solved and a control law is calculated also in each step.

The Nonlinear Regulator problem [17] for a system represented in the State-Dependent Riccati Equation form with infinite horizon, can be formulated minimizing the cost functional given by

$$J(x_0, u) = \frac{1}{2}\int_{t_0}^{\infty}(x^T Q(x)x + u^T R(x)u\,)dt \qquad (1)$$

with the state $x \in \Re^n$ and control $u \in \Re^m$ subject to the nonlinear system constraints given by

$$\dot{x} = f(x) + B(x)u$$
$$y = C(x)x \qquad (2)$$
$$x(0) = x_0$$

where $B \in \Re^{nxm}$ and C are the system input and the output matrices, and $y \in \Re^s$ ($\Re^s$ is the dimension of the output vector of the system). The vector initial conditions is x(0), $Q(x) \in \Re^{nxn}$ and $R(x) \in \Re^{mxm}$ are

the weight matrix semi defined positive and defined positive.

Applying a direct parameterization to transform the nonlinear system into State Dependent Coefficients (SDC) representation, the dynamic equations of the system with control can be write in the form

$$\dot{x} = A(x)x + B(x)u \qquad (3)$$

with $f(x) = A(x)x$, where $A \in \Re^{nxn}$ is the state matrix. By and large $A(x)$ is not unique. In fact there are an infinite number of parameterizations for SDC representation. This is true provided there are at least two parameterizations for all $0 \le \alpha \le 1$ satisfying

$$\alpha A_1(x)x + (1-\alpha)A_2(x)x = \alpha f(x) + (1-\alpha)f(x) = f(x) \qquad (4)$$

The choice of parameterizations to be made must be appropriate in accordance with the control system of interest. An important factor for this choice is not violating the controllability of the system, i.e., the matrix controllability state dependent $[B(x)A(x)B(x) \dots A^{n-1}(x)B(x)]$ must be full rank.

The state-dependent algebraic Riccati equation (SDARE) can be obtained applying the conditions for optimality of the variational calculus. As a result, the Hamiltonian for the optimal control problem given by Eq. (1) and (2) is given by

$$H(x,u,\lambda) = \frac{1}{2}(x^T Q(x)x + u^T R(x)u\,) + \lambda^T(A(x)x + B(x)u) \qquad (5)$$

where $\lambda \in \Re^n$ is the Lagrange multiplier.

Applying to the Eq.(5) the necessary conditions for the optimal control given by $\dot{x} = \frac{\partial H}{\partial \lambda}$, $\frac{\partial H}{\partial u} = 0$ and $\dot{\lambda} = -\frac{\partial H}{\partial x}$, one gets

$$\dot{\lambda} = -Q(x)x - \frac{1}{2}x^T\frac{\partial Q(x)}{\partial x}x - \frac{1}{2}u^T\frac{\partial R(x)}{\partial x}u - \left[\frac{\partial(A(x)x)}{\partial x}\right]^T\lambda$$
$$- \left[\frac{\partial(B(x)u)}{\partial x}\right]^T\lambda \quad (6)$$

$$\dot{x} = A(x)x + B(x)u \qquad (7)$$

$$0 = R(x)u + B^T(x)\lambda \qquad (8)$$

Assuming the co-state in the form $\lambda = P(x)x$, which is dependent of the state, from Eq.(8) one obtains the feedback control law

$$u = -R^{-1}(x)B^T(x)P(x)x \qquad (9)$$

Substituting this result into Eq. (7) one gets

$$\dot{x} = A(x)x - B(x)R^{-1}(x)B^T(x)P(x)x \qquad (10)$$

To find the function P (x) one differentiates $\lambda = P(x)x$ with respect the time along the path from which one gets

$$\dot{\lambda} = \dot{P}(x)x + P(x)\dot{x}$$
$$= \dot{P}(x)x + P(x)A(x)x$$
$$- P(x)B(x)R^{-1}(x)B^T(x)P(x)x \qquad (11)$$

Substituting Eq.(11) in the first necessary condition of optimal control (Eq.6) one obtains

$$\dot{P}(x)x + P(x)A(x)x - P(x)B(x)R^{-1}(x)B^T(x)P(x)x$$
$$= -Q(x)x - \frac{1}{2}x^T\frac{\partial Q(x)}{\partial x}x - \frac{1}{2}u^T\frac{\partial R(x)}{\partial x}u$$
$$- \left[A(x) + \frac{\partial(A(x)x)}{\partial x}x\right]^T P(x)x$$
$$- \left[\frac{\partial(B(x)u)}{\partial x}\right]^T P(x)x \qquad (12)$$

Arranging the terms more appropriately one has

$$\dot{P}(x)x + \frac{1}{2}x^T\frac{\partial Q(x)}{\partial x}x + \frac{1}{2}u^T\frac{\partial R(x)}{\partial x}u + x^T\left[\frac{\partial(A(x))}{\partial x}\right]^T P(x)x$$
$$+ \left[\frac{\partial(B(x)u)}{\partial x}\right]^T P(x)$$
$$+ [P(x)A(x) + A^T(x)P(x) - P(x)B(x)R^{-1}(x)B^T(x)P(x) + Q(x)]x$$
$$= 0 \qquad (13)$$

In order to satisfy the equality of Eq.(13) one obtains two important relations. The first one is state-dependent algebraic Riccati equation (SDARE) which solution is P(x) given by

$$P(x)A(x) + A^T(x)P(x) - P(x)B(x)R^{-1}(x)B^T(x)P(x) + Q(x)$$
$$= 0 \qquad (14)$$

The second one is the necessary condition of optimality which must be satisfied, given by

$$\dot{P}(x)x + \frac{1}{2}x^T\frac{\partial Q(x)}{\partial x}x + \frac{1}{2}u^T\frac{\partial R(x)}{\partial x}u + x^T\left[\frac{\partial(A(x))}{\partial x}\right]^T P(x)x$$
$$+ \left[\frac{\partial(B(x)u)}{\partial x}\right]^T P(x)x$$
$$= 0 \qquad (15)$$

For the infinite time problem and considering the standard Linear Quadratic Regulator (LQR) problem, this is a condition that satisfies the optimality of the solution suboptimal control.

Finally, the nonlinear control law fed back by the states has the following form

$$u = -S(x)x, \; with \; S(x) = R^{-1}(x)B^T(x)P(x) \qquad (16)$$

For some special cases, such as systems with little dependence on the state or with few state variables, Eq. (14) can be solved analytically. On the other hand, for more complex systems the numerical solution can be obtained using an adequate sampling rate. It is assumed that the parameterization of the coefficients dependent on the state is chosen so that the pair (A (x), B (x)) and (C (x) A (x)) are in the linear sense for all x belonging to the neighbourhood about the origin, point to point, stabilizable and detectable, respectively. Then the SDRE nonlinear regulator produces a closed loop solution that is locally asymptotically stable. An important factor of the SDRE method is that it does not cancel the benefits that result from the nonlinearities of the dynamic system, because, it is not require inversion and no dynamic feedback linearization of the nonlinear system.

The Nonlinear State Estimation problem [18] is analogous to linear method. Using the dual formulation to the nonlinear quadratic regulator problem, a nonlinear estimator can formed, assuming that the measurement is a nonlinear function of x such that

$$y = g(x) \qquad (17)$$

One needs to form a state dependent coefficient measurement

$$y = C(x)x \qquad (18)$$

For the optimal estimation problem, the cost function can be of the form

$$Min.(\hat{x}) J$$
$$= \frac{1}{2}E\{\int_{t_0}^{\infty}[(x - \hat{x})^T\Gamma^TW^{-1}\Gamma(x - \hat{x}) + (y - C\hat{x})^TV^{-1}(x$$
$$- \hat{x})]\}dt \qquad (19)$$

Subject to the nonlinear differential constraints

$$\dot{x} = A(x)x + \Gamma w \qquad (20)$$
$$y = C(x)x + v \qquad (21)$$

where w and υ are the Gaussian zero-mean white process noise and measurement noise with variance given by $W = E[w^T w]$ and $V = E[v^T v]$, respectively. The SDC matrices of measurement have to satisfy the same conditions for the SDC regulator problem.

Using the dual of the regulator problem, the SDRE nonlinear estimator is given by

$$\frac{d\hat{x}}{dt} = A(\hat{x})\hat{x} + K_f(y + \hat{y}) \qquad (22)$$
$$\hat{y} = C(\hat{x})\hat{x} \qquad (23)$$
$$K_f = Y(x)C^T(\hat{x})V^{-1} \qquad (23)$$

Where Y (x) is the positive semi definite solution of another state-dependent algebraic Riccati equation (SDARE) given by

$$A(\hat{x})Y(x) + Y(x)A^T(\hat{x}) - Y(x)C^T(\hat{x})V^{-1}C(\hat{x})Y(x) + \Gamma^TW\Gamma$$
$$= 0 \qquad (24)$$

The estimator will not be optimal unless a time dependent parameterization meeting the optimality condition is used. However, not requiring optimality may still result in a sufficient estimator. The matrix A($\hat{x}$) is calculated in every step after estimating the states $\hat{x}$ and calculates K_f and Y(x). The conjunction of the SDRE and Kalman filter techniques is quite adequate for on-board computer implementations.

However, here the Kalman filter is only implemented in the normal mode of operation where the sensor noise can affect the fine pointing accuracy.

Simulator Model

Figure 1 show the INPE 3-D simulator which has a disk-shaped platform, supported on a plane with a spherical air bearing. Considering that the simulator is not complete build, one assumes that there are three reaction wheel and configuration of gas jets capable to perform maneuver around the three axes and that there are three angular velocities sensor, like gyros. Apart from the difficulty of reproducing zero gravity and torque free condition, modeling a 3-D simulator, basically, follows the same step of modeling a rigid satellite with rotation in three axes free in space.
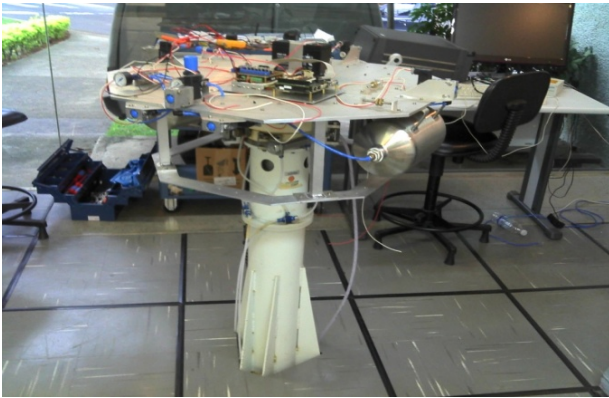

FIG. 1 INPE 3-D SIMULATOR WITH GAS JETS AND THREE REACTION WHEELS

The orientation of the platform is given by the body reference system F_b with respect to inertial reference system F_I considering the principal axes of inertia and using the Euler angles $(\theta_1, \theta_2, \theta_3)$ in the sequence 3-2-1, to guarantee that there is no singularity in the simulator attitude rotation. The equations of motions are obtained using Euler′s angular moment theorem given by

$$\dot{\vec{h}} = \vec{g} \tag{25}$$

where $\vec{g}$ and $\vec{h}$ are the torque and the angular moment of the system, which is given by

$$\vec{h} = I\vec{\omega} + I_w\left(\vec{\Omega} + \vec{\omega}\right) \tag{26}$$

where I = diag (I_{11}, I_{22}, I_{33}) is the system matrix inertia moment, $\vec{\omega}$ is the angular velocity of the platform, $\vec{I}_w$ = diag (I_{w1}, I_{w2}, I_{w3}) is the reaction wheel matrix inertia moment and Ω = (Ω_1, Ω_2, Ω_3) are the reaction wheel angular velocity.

Differentiating Eq. (26) and considering that the angular velocity of F_b is $\vec{\omega}$ and that the external torque equal to zero, one has

$$\dot{\vec{h}} + \vec{\omega}^x\vec{h} = 0 \tag{27}$$

Substituting Eq.(26) into Eq.(27), the angular velocity of the system is

$$\dot{\vec{\omega}} = \left(I + I_w\right)^{-1}\left[-\vec{\omega}^x\left(I + I_w\right)\vec{\omega} - \vec{\omega}^x I_w\vec{\Omega} - I_w\dot{\vec{\Omega}}\right] \tag{28}$$

The simulator attitude as function of the angular velocity is

$$\begin{pmatrix}\dot{\theta}_1 \\ \dot{\theta}_2 \\ \dot{\theta}_3\end{pmatrix} = \begin{pmatrix} 0 & \sin\theta_3/\cos\theta_2 & \cos\theta_3/\cos\theta_2 \\ 0 & \cos\theta_3 & -\sin\theta_3 \\ 1 & \sin\theta_3\sin\theta_2/\cos\theta_2 & \cos\theta_3\sin\theta_2/\cos\theta_2 \end{pmatrix}\begin{pmatrix}\omega_1 \\ \omega_2 \\ \omega_3\end{pmatrix} \tag{29}$$

In order to design the attitude control system based on reaction wheel and gas jets actuators to perform a large angle manoeuvre, it is important to have in mind that each control algorithm is designed based on two different a set of equations of motions. In other words, the gas jets are applied to reduce the high angular velocity and the reaction wheel is used to control in the fine pointing accuracy mode. As a result, for each operation mode one has different matrices A(x) and the respective matrix B associated with it. The C matrix, although depend on the sensor type is assumed unity for simplicity.

In the fine pointing mode where the reaction wheel is the actuator, the state's x are $(\theta_1\ \theta_2\ \theta_3\ \omega_1\ \omega_2\ \omega_3)^T$ and the control u is$(\dot{\Omega}_1\ \dot{\Omega}_2\ \dot{\Omega}_3)^T$, the matrices A(x) and B are given by

$$A(x) = \begin{pmatrix} & & & 0 & \dfrac{\operatorname{sen}\theta_3}{\cos\theta_2} & \dfrac{\cos\theta_3}{\cos\theta_2} \\ 0\ 0\ 0 & 0 & \cos\theta_3 & -\operatorname{sen}\theta_3 \\ 0\ 0\ 0 & 1 & \dfrac{\operatorname{sen}\theta_3\operatorname{sen}\theta_2}{\cos\theta_2} & \dfrac{\cos\theta_3\operatorname{sen}\theta_2}{\cos\theta_2} \\ 0\ 0\ 0 & 0 & & \\ 0\ 0\ 0 & \dfrac{-I_{11}\omega_3 + I_w\Omega_3}{(I_{22}+I_w)} & \dfrac{I_{22}\omega_3 - I_w\Omega_3}{(I_{11}+I_w)} & \dfrac{-I_{33}\omega_2 + I_w\Omega_2}{(I_{11}+I_w)} \\ 0\ 0\ 0 & \dfrac{I_{11}\omega_2 - I_w\Omega_2}{(I_{33}+I_w)} & 0 & \dfrac{I_{33}\omega_1 - I_w\Omega_1}{(I_{22}+I_w)} \\ & & \dfrac{-I_{22}\omega_1 + I_w\Omega_1}{(I_{33}+I_w)} & 0 \end{pmatrix}$$

$$B = \begin{pmatrix} \dfrac{-I_w}{(I_{11}+I_w)} & 0 & 0 \\ 0 & \dfrac{-I_w}{(I_{22}+I_w)} & 0 \\ 0 & 0 & \dfrac{-I_w}{(I_{33}+I_w)} \end{pmatrix} \tag{30}$$

One knows that the reaction wheel generates internal torques and the attitude control is performed by exchanging angular moment between the reaction

wheel and the satellite. On the other hand, gas jets generates external torque M given by

$$M_{Pi} = -T_i.d_i \qquad (31)$$

where M_{Pi} is the torque generated around the "i" axis due to the force T_i applied at distance d_i from the rotation axis.

In the angular reduction mode one uses gas jets and the reaction wheel is locked, therefore, its acceleration and angular velocity are zero and the satellite angular velocity is given by

$$\dot{\omega} = (I + I_w)^{-1}[-\omega^x(I + I_w)\omega - T_i.d_i] \qquad (32)$$

The states x are $(\theta_1 \; \theta_2 \; \theta_3 \; \omega_1 \; \omega_2 \; \omega_3)^T$ and the control u is $(T_1 \; T_2 \; T_3)^T$, therefore, the matrices A(x) and B are given by

$$A = \begin{pmatrix} & & & 0 & \dfrac{sen\theta_3}{cos\theta_2} & \dfrac{cos\theta_3}{cos\theta_2} \\ 0\,0\,0 & & 0 & cos\theta_3 & -sen\theta_3 \\ 0\,0\,0 & & 1 & \dfrac{sen\theta_3 sen\theta_2}{cos\theta_2} & \dfrac{cos\theta_3 sen\theta_2}{cos\theta_2} \\ 0\,0\,0 & & 0 & & \\ 0\,0\,0 & \dfrac{-I_{11}\omega_3}{(I_{22}+I_w)} & \dfrac{I_{22}\omega_3}{(I_{11}+I_w)} & \dfrac{-I_{33}\omega_2}{(I_{11}+I_w)} \\ 0\,0\,0 & \dfrac{I_{11}\omega_2}{(I_{33}+I_w)} & 0 & \dfrac{I_{33}\omega_1}{(I_{22}+I_w)} \\ & & \dfrac{-I_{22}\omega_1}{(I_{33}+I_w)} & 0 & \end{pmatrix}$$

$$B = \begin{pmatrix} \dfrac{-d_1}{(I_{11}+I_w)} & 0 & 0 \\ 0 & \dfrac{-d_2}{(I_{22}+I_w)} & 0 \\ 0 & 0 & \dfrac{-d_3}{(I_{33}+I_w)} \end{pmatrix} \qquad (33)$$

Criterion for Changing the Actuator

The implementation of the SDRE algorithm in real time has becomes more realistic due to the commercial micro processor is getting faster [19]. Here, the control system has to deal with two operation modes where the first one is the reduction of high angular velocity using gas jets and the second one is the control in three axes with fine pointing accuracy using reaction wheel. As a result, it is necessary to establish a criterion to change from one actuator to another. This criterion of course is function of the satellite space mission and the control system equipments. For example, from the angular velocity reduction mode to the normal mode of operation the criterion could be associated with the amount of energy that the reaction wheel can support before being saturated or with the minimum and maximum values of the gas jets capacity. The criterion used here is based on the total potential and kinetic energy of the system, which means that when the system reaches a certain level of

energy the control algorithm change the type of actuator.

The potential energy associated with the angular displacement is

$$U = K_u\Delta\theta^2 \qquad (34)$$

where K_u is a constant and $\Delta\theta$ represent the angular displacement of the simulator.

The simulator kinetic energy is given by

$$K = K_c w^2 \qquad (35)$$

where K_c is a constant and w is the angular velocity of the simulator. It is important to say that the constants K_u and K_c must be such to maintain the total system energy compatibles. Besides, the level of energy can be changed according with the kind of control system to be evaluated. Here one assumes certain level of energy just for simulation purpose.

Simulation Results

The superiority of the SDRE method to perform a regulation and tracking large angle manoeuvre over the LQR method has been demonstrated in [10]. Here, the simulation is to demonstrate the ability of the SDRE plus Kalman filter techniques to control a non-linear plant based on control algorithm using the previously criterion of energy to change from the gas jets to reaction wheel action. The simulator platform can accommodate various satellites components; like sensors, actuators, computers and its respective interface and electronic. Therefore, the inertia moments of the simulator depend on the equipments distribution over it. Here, one assumes and uses the following typical inertia moment for the simulator: I_{11} = I_{22} = 1.17 Kg·m^2 and I_{33} = 1.13 Kg·m^2; and for the reaction wheel I_x = I_y = I_z = 0.0018 Kg·m^2. The maximum and minimum gas jet torque used is 10 Nm and the total amount of system energy to change from gas jets to reaction wheel is 0.5J. In the fine pointing mode the typical sensor noises used are theta = 0.2 (deg) and rate theta = 0.1 (deg/s).

The SDRE controller has to perform a large angle maneuver which begins on 0º and in the end it has to tracking a angular reference of (100, 50, 70) deg. The controller performance requirements are small overshoot and quick time of response. The controller robustness is associated with its ability to perform big tracking maneuver apart from the perturbations due to sensor noise and plant nonlinear terms. Figures 2 and 3 show the angular displacement and angular velocity when the SDRE controller performs the

simulator large maneuver from 0º and it has to follow a angular reference of (100, 50, 70) deg.. One observes that at the maneuver end the non-linear terms of the plant are relevant. The SDRE controller is able to get the reference in about 250s. It is important to say that this performance is a function the weighting matrices of the SDRE controllers.
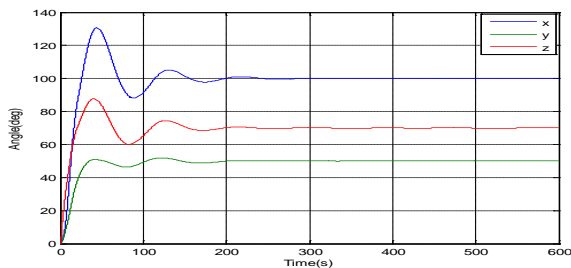

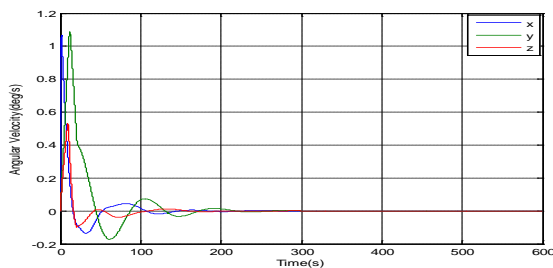FIG. 2 SIMULATOR ANGULAR DISPLACEMENT IN X, Y AND Z

FIG. 3 SIMULATOR ANGULAR VELOCITIES IN X, Y, AND Z

Figures 4 and 5 show the SDRE controller the transition phase of the previously manoeuvre where the torque is only due to the gas jets and the torque is only due to the reaction wheel, respectively.
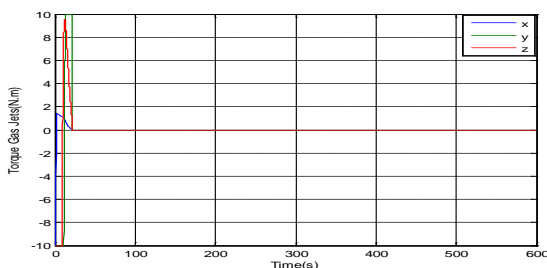

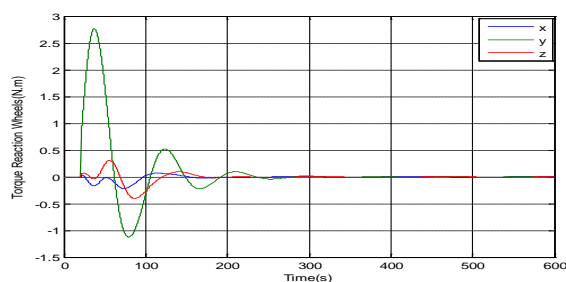FIG. 4 SDRE CONTROLLER USING TORQUE DUE TO THE GAS JETS

FIG. 5 SDRE CONTROLLER USING TORQUE DUE TO THE REACTION WHEEL

Figure 6 shows that the gas jets stop acting and the reaction wheel starting acting when the criterion for changing actuators is equal the system total energy given by 0.5J.
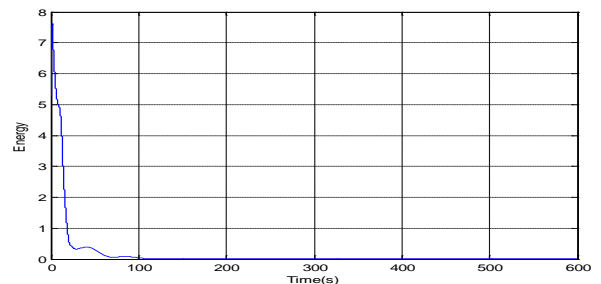

FIG. 6 CRITERION FOR CHANGING ACTUATORS IS 0.5J

From simulations one observes that at the beginning of the manoeuvre the level of energy is high, because the simulator is far from the final attitude to be follow. As a result, the control algorithm selects as actuators the thrusters in order to deal with high angular velocities reduction. On the other hands, when the simulator reaches the reference attitude, the total energy decreases rapidly and the control algorithm selects as actuators the reaction wheels, in order to perform fine pointing adjustment of the simulator.

Finally, it is important to say that the criterion for changing the actuated based on the energy value defined in the program was established just to provide a good visualization of the torques from the two actuators during the simulation. However, further study of this actuated change can be done based in other criterion like optimization of control parameters of the simulator as time, fuel, reaction wheel speed and pointing accuracy.

Conclusions

In this paper one develops a general 3-D simulator non linear model, once it only depends on the inertia moment of the system. The matlab/simulink model is used to investigate large angle tracking manoeuvre in order to design a control algorithm based on the gas jet and reaction wheel, where the first actuator is used to reduce high angular velocity and the second one to perform fine pointing control. The criterion used to change from gas jet to reaction wheel action is based on the potential plus the kinetic energy of the system. Therefore, the transition between modes of operation occurs when the system reaches a certain level of energy. The nonlinear controller design uses the conjunction of the SDRE (State Dependent Riccati Equation) and Kalman filter methods to deal with high

nonlinear simulator plant and noise. Simulations have demonstrated the good performance and robustness of the SDRE controller to perform large angle tracking manoeuvre considering as project trade-off the settling time and fuel consumption. The investigation has also shown that SDRE control algorithm is potentially applicable to be implemented in satellite on board computer, once the SDRE controller gains can be designed off line and they are constant.

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